I declare that I have read this final year project report and in my opinion, this final year project is sufficient in terms of scope and quality for the purpose to be awarded the Degree of Bachelor Engineering (Electrical-Mechatronics).

Signature : ……..

Name : Dr Mohamad Shukri bin Zainal Abidin

Date : 26th June 2015

DESIGN AND DEVELOPMENT OF CAPILLARY IRRIGATION SYSTEM CONTROLLER

SALWA BINTI MOHSIN

A final year project report submitted in partial fulfillment
of the requirements for the award of the degree of
Bachelor of Engineering (Electrical-Mechatronics)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JUNE 2015

I declare that this final year project report entitled “Design and Development of Capillary Irrigation System Controller” is the result of my own research except as cited in the references. The final year project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……..

Name : Salwa binti Mohsin

Date : 26th June 2015

To my beloved friends and family

ACKNOWLEDGEMENT

Conducting the research of this project was truly a great experience. I was able to implement my classroom theories learnt as well as learned even more about the scope of my research. I also gained many life lessons that I could have never learn in class.

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Last but not least, I would like to thank my friends and family who has been there for me in giving me mental and physical support throughout this tough time.

ABSTRACT

Water crisis is becoming an issue in the 21st century where freshwater consumption is increasing worldwide. 70 percent of freshwater is consumed by the agriculture sector for irrigation purposes. With low efficiency systems implemented, billions liters of water is wasted. This project is conducted to develop capillary irrigation system controller for water saving to reduce the water consumption in irrigation. The irrigation method implemented is an underground system to reduce the water loss using capillary irrigation. This project consist of obtaining the actual crop evapotranspiration value using selected sensors to identify the crops' water needs. With the data obtained, a controller will be implemented into the system. This system will supply water to the crop only according to its needs to save water.

ABSTRAK

Krisis air menjadi isu pada abad ke- 21 di mana penggunaan air semakin meningkat di seluruh dunia. 70 peratus daripada air digunakan oleh sektor pertanian untuk tujuan pengairan. Penggunaan sistem yang kurang efisyen menyebabkan berbilion liter air dibazirkan. Projek ini bertujuan untuk membangunkan sistem pengawalan kapilari untuk pengairan air yang dapat mengurangkan penggunaan air untuk pengairan. Pengairan dilaksanakan menggunakan kaedah bawah tanah untuk mengurangkan kehilangan air dengan mengaplikasikan pengairan kapilari. Projek ini mendapatkan nilai penyejatpeluhan tanaman menggunakan sensor yang terpilih untuk mengenal pasti keperluan air tanaman. Dengan data yang diperolehi, satu kawalan akan diaplikasikan ke dalam sistem. Sistem ini akan membekalkan air kepada tanaman hanya mengikut keperluan untuk penjimatan air.

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LIST OF SYMBOLS

G	-	G-force (Gravitational force)
V	-	Volts
˚C	-	Degree Celsius
%	-	Percent

LIST OF ABBREVIATIONS

ANN	-	Artificial Neural Network
ET	-	Evapotranspiration
PCB	-	Printed Circuit Board
UTM	-	Universiti Teknologi Malaysia

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Agriculture is the cultivation of soil, plants, animals and other life forms in the purpose of growing crops, providing food, wool and other products. The growing of the global population has made the agriculture an important sector in international trade [1]. In fact, the agriculture industry has played an important growth in the Malaysian economy ever since it aided in the recovery of the 1998 financial crisis [2]. Strengthening the agriculture industry, Malaysia has revived this sector in the Ninth Malaysian Plan (2006-2010) as the third engine of growth.

> A *New Agriculture* concept implemented involved large-scale commercial farming, the wider application of modern technology, production of high quality and value-added products, unlocking the potential in biotechnology, increased convergence with information and communications technology (ICT), and the participation of entrepreneurial farmers and skilled workforce.
>
> (Ninth Malaysia Plan (2006-2010), 2006:81)

Irrigation is widely associated with agriculture where water is applied to the land for the purpose of crop productions. Paddy fields are common in Malaysia as it supplies the country's staple food. The development of irrigation was top priority in the 1980s to increase the rice cultivation productivity. As a result, the land that has been invested with irrigation and drainage infrastructures shows a tremendous growth in the crop outcome. In 2010, these areas accounted for 71.3% of the total national rice production [3].

Statistics indicates that 70 percent to 80 percent of the global freshwater is used in the agriculture sector for irrigation [4]. Figure 1.1 shows the global water use by sector in 2002. In 2005, Malaysia has an estimated water withdrawal of 13.21 billion liters. Figure 1.2 shows the Malaysian percentage of water use according to sector. Observing Figure 1.3, the agriculture (irrigation + livestock) sector takes 34% of the total water consumption, 4.52 billion liters. In 1999, the irrigation efficiency was identified between 35 to 45 percent. Assuming the efficiency rate is the same in 2005, 1.582 to 2.034 billion liters of freshwater has been wasted [5].

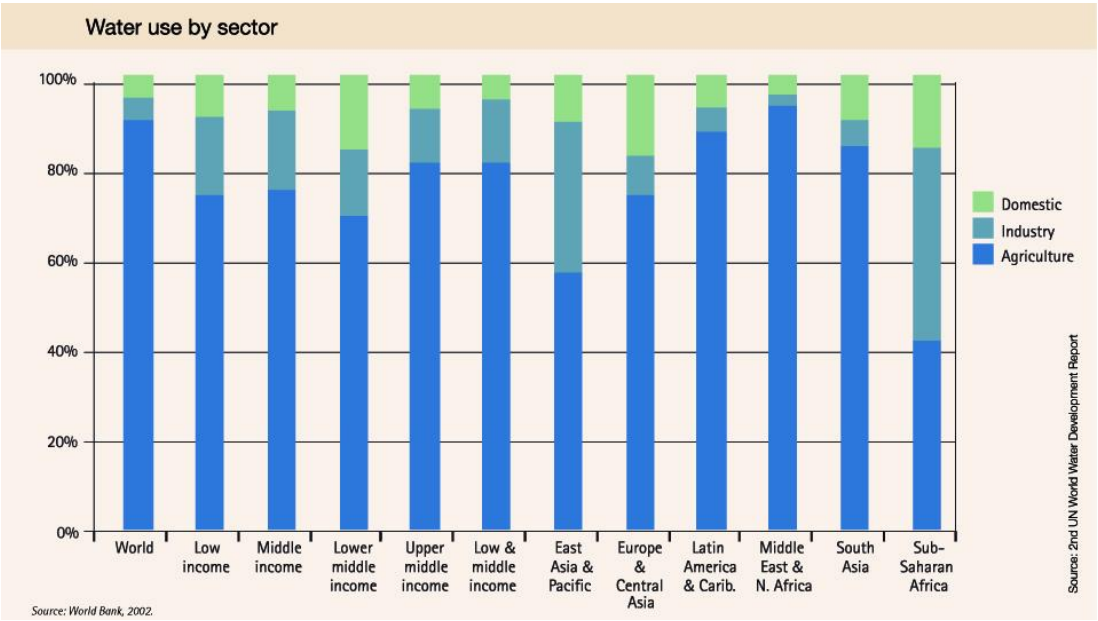

Figure 1.1 Global water use by sector in 2002

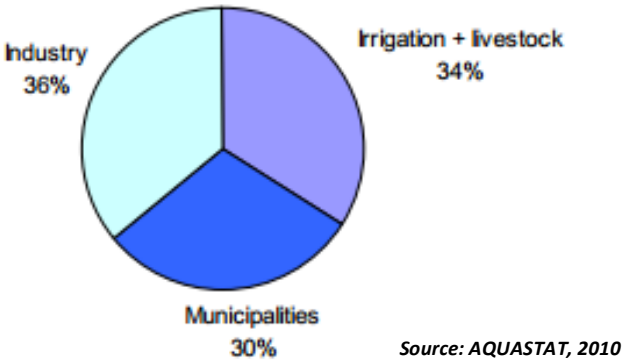

Figure 1.2 Malaysia water withdrawal by sector in 2005

In the recent years, Malaysia is facing water crisis and its effects are becoming significant. The water crisis issue is predicted to take a toll on the national economic activities. If this issue is unresolved, it will lead to the depletion of the agriculture outcome. Subsequently, this will lead to food shortage and rising commodity prices. As agriculture is one of the main international trade for Malaysia, the reduction in the production will cause economic losses to the country. Furthermore, the risk of water shortage will force Malaysia to increase the amount of food imported. This situation has been observed in the late 2010 where the worldwide wheat prices has increased early 2011 following the drought that damaged the wheat production [6].

In general, plants absorb their nutrients and water from the ground. Water is transported to the rest of the plant via capillary action. Capillary action is an important process in plants where the liquid cohesion (a force binding the liquid together) and adhesion (a force binding the liquid and another surface together) is greater than the gravitational force, enabling liquid to flow with no assistance and against the gravity pull to rise in narrow tubes. This process in plants is able to be observed by cutting the end of a celery stalk and immerse it in a glass of dyed water. Leaving it overnight, the leaves of the celery has changed according to the colour of the water dye. This short experiment shows that the dyed water had undergo capillary action where it has been transported in the thin tubes in plants to the leaves. Figure 1.3 shows the how the celery immersed in dyed water has changed overnight.

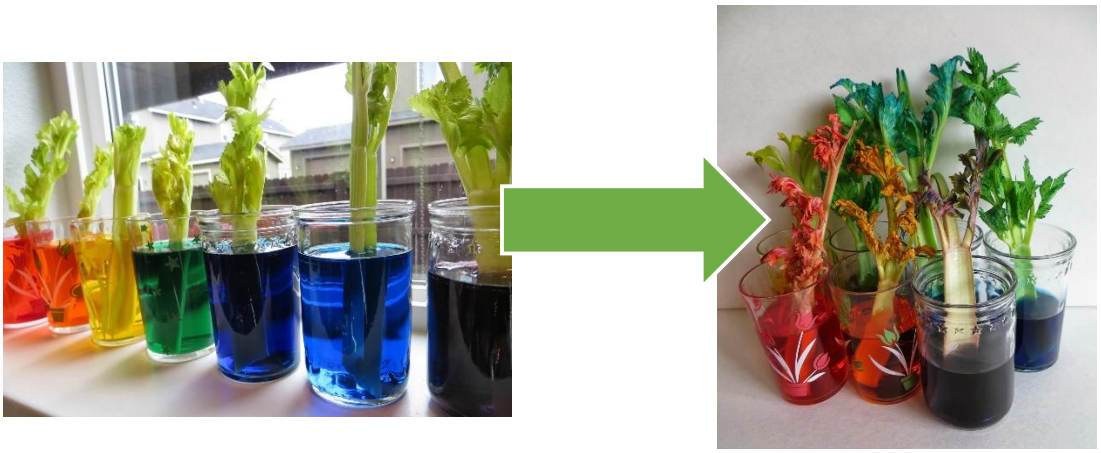

Figure 1.3 Overnight changes in celery leaf immersed in dyed water

1.2 Problem Statement

Irrigation is necessary in agriculture as it allows unsuitable area for crop production possible for crop plantation production. Besides that, it reduces the crop stress that the plant undergo in an event that rainfall is unable to provide sufficient moisture to the crop. The reliable water source that irrigation provides to the crop plantation shows a significant increase in crop quality and production. This is particularly noticeable for vegetable crops [18].

Despite the many options available for irrigation, many farmers opt for the cheapest technology available such as flood irrigation. This is due to the necessity to irrigate hundreds of acres of crop production. Although the cost of installation is inexpensive, it is one of the most inefficient irrigation methods. Low efficiency in irrigation can lead to billions of litres of water wasted. Researchers discovered that even by reducing 10 percent of water consumption in irrigation, we are able to save more than other consumers combined [19].

The current capillary system implemented uses capillary matting or water well pots. Both methods requires the farmers to ensure the water needs to be applied at the potting mix. There is no fixed amount on the number of times to check the water supply as it depends on the plants needs to be replenished. The purpose of the capillary system is to ensure continuous water supply to the crop. Though, the inconsistent watering time is not practical for farmers as they need to monitor more than just several pots. The system will be more practical if it is able to ensure the water supply in the potting mix is constantly available without the need for farmers to regularly check them and if it is able to provide the water supply according to the plants needs [20].

1.3 Research Objectives

The objectives of the research project are:

I. To develop a capillary irrigation system using water string.
II. To identify the evapotranspiration rate of the plant.
III. To develop an irrigation system controller based on plant water demand.

1.4 Scope of Project

There are five main scopes in conducting this research project which are:

I. Studying the cultivation of plants in horticulture, mainly short term vegetable crops within greenhouse application.
II. Identifying the temperature and humidity demand in plants (climate change), its physiology and the optimum time for plant watering.
III. Choosing suitable type of sensors to be used in data acquisition and calibrate them.

IV. Designing a control system for optimum water absorption by plants and reduce water usage in irrigation agriculture.

V. Testing of system on plant and analyze its outcome.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses the research conducted and available technologies related to irrigation in agriculture for the development of this project. The current technologies used in the field are studied to identify the needs in the systems, the efficiency rate and aspects that need to be improved. Apart from that, in the literature review explains the method used to estimate the crop water requirement as described by researches that had been conducted previously.

2.2 Conventional Irrigation Method

There are two general categories of irrigation which are surface irrigation and subsurface irrigation. There are three main widely popular irrigation methods in

agriculture which are sprinkler irrigation, drip irrigation capillary. The type of water irrigation implemented to the crop varies according the water availability, soil characteristics, crop requirements, crop and cultural practices [4].

2.2.1 Surface irrigation

In surface irrigation, water is flowed into the crop field from a stream of river or water source. The most common type of surface irrigation implemented in Malaysian agriculture is the flood irrigation. This type of irrigation system is commonly found in the paddy fields. Flood irrigation or also known as basin irrigation is when the water is supplied to the irrigated with minimal field preparation [4] and the water depth is controlled by farmers [5]. Unfortunately, the efficiency of this irrigation method was identified to be between 35 to 45 percent [5]. Figure 2.1 shows the paddy field which uses the flood irrigation system.

Figure 2.1 Flood irrigation in paddy field

Furrow irrigation applied the similar concept as the flood irrigation [7]. However, in the furrow irrigation technique water is directed to lower level pathways

that can be constructed using simple farming machinery [5]. Figure 2.2 shows the furrow type of surface irrigation.

Figure 2.2 Furrow surface irrigation

2.2.2 Subsurface irrigation

This type of irrigation is the least popular among all the irrigation method available. The crop area receives the water flowed directly to the crop root-zone. The water is typically channeled through pipes buried in the soil [5]. Figure 2.3 shows an example of a subsurface irrigation method.

Figure 2.3 Set up of the subsurface irrigation method

2.2.3 Sprinkler irrigation

Sprinkler type irrigation is one of the popular irrigation system implemented in small crop plantations. The concept of sprinkler irrigation is watering the crop imitating rainfall. Water is flowed under pressure in the pipelines to the sprinkler heads [5]. There are two types of movements for the sprinkler: static and rotation. The type of sprinkler implemented depends on the type of crop it is watering.

Water is usually irrigated using a timer where the sprinklers will turn on at a certain frequency or time interval. The disadvantages of this irrigation method is that it has a high implementation cost and there is a non-restricted water supply. However, using the sprinkler irrigation requires less man power as compared to other irrigation systems [7].

Figure 2.4 Sprinkler irrigation

2.2.4 Drip irrigation

Drip irrigation provides water to the crop by installing microsprayers located directly a few centimeters above the crop root. Although the cost of fixing this irrigation system is rather costly, the water is supplied directly to the crop root area. Hence, the water loss is minimal due to evaporation [7]. The cost of fertilizers and the labour is reduced with fertigation (irrigation of liquid dissolved with nutrients). A drip irrigation system mainly consist of the emitters (microsprayers); lateral line, sub main and main line (water flow from source to the crop area); water valve, filter and water supply control [8].

Figure 2.5 Drip irrigation

2.2.5 Capillary irrigation

Capillary irrigation or known as capillary watering system takes advantage of the natural capillary action. It applies an underground irrigation method where the water supplied to the crop is not exposed to the air. This technique supplies water continuously to the crop, thus causing the crop to be highly productive. Furthermore, it uses 50 percent less water with an increase in the food production. This irrigation method is similar with wicking where it is mostly found in dry regions [15].

2.3 Efficiency Rate and Water Loss in Agriculture

2.3.1 Efficiency rate and Distribution Uniformity

The efficiency of water use in agriculture is to express the relationship between the input and output of the system where in this situation, the input is the water irrigated and output is crop production, economic return or amount of water retained in the root-zone. Figure 2.6 shows the framework for water use efficiency in agriculture. Nevertheless, calculating the efficiency theoretically is different in the real application. In the actual crop application, there is a need for other water source that may supply water to the crop such as rainfall [9].

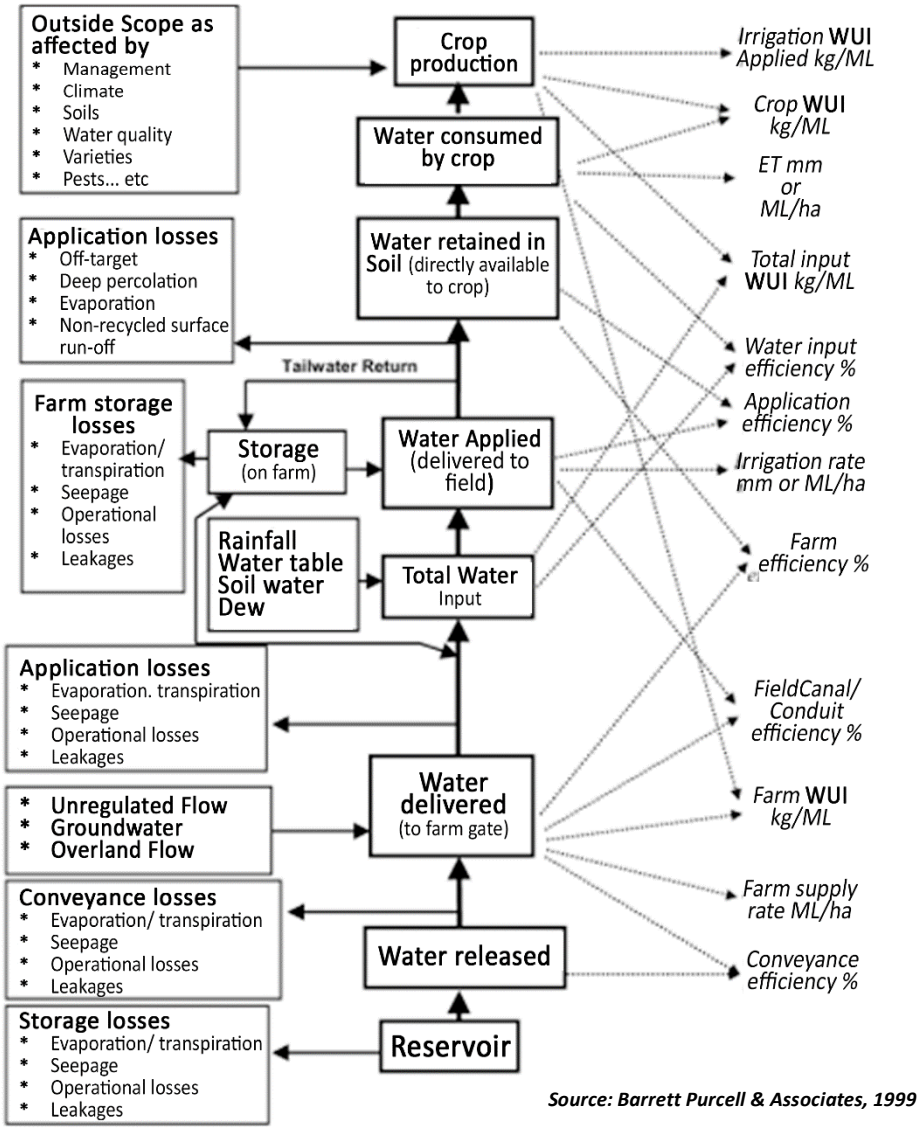

Figure 2.6 Water use efficiency framework

Distribution uniformity refers to the even water distribution in irrigation [9]. The even water distribution in irrigation is important as it determines the condition of the crop. Figure 2.7 shows the irrigation efficiency for surface and sprinkler irrigation.

E_a refers to the application efficiency while E_d refers to the distribution efficiency. As observed in surface irrigation, the application efficiency value decreases as the depth of water infiltrated increases beyond the depth required. This is due to the over irrigation causing crop stress. The similar situation can also be observed in the sprinkler irrigation. Example H illustrates the ideal water irrigation as compared to example G and I with a balance in the distribution efficiency and application efficiency. Unable to meet the ideal distribution efficiency and application efficiency may cause crop stress. Crops under stress will affect the crop production [10].

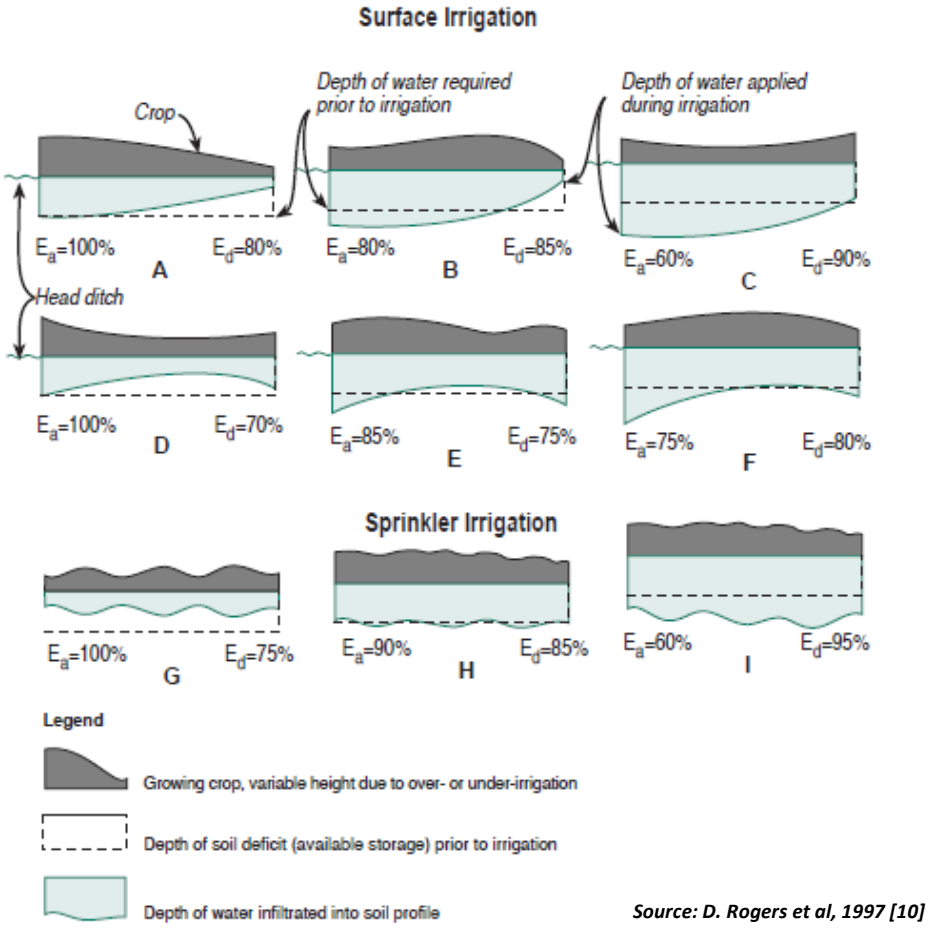

Figure 2.7 Example of irrigation efficiency for surface irrigation and sprinkler irrigation

2.3.2 Water Loss

There are several categories for water losses in irrigation which are air losses, surface/ atmospheric losses and canopy losses. Air losses are more common in sprinkler overhead irrigation system from air drift and droplet evaporation. Evapotranspiration of unintended crops such as weeds, evaporation from open water, surface runoff and soil evaporation are examples of surface loss in the field [10].

2.4 Evapotranspiration (ET)

Evapotranspiration is a term derived from evaporation and transpiration, which both process occurs in agriculture. This term is a phenomena of water loss. Evaporation is the action of water vapourization from the ground or vegetation to the air while transpiration is fundamentally water evaporation taking place from the leaves.

The evapotranspiration rate in a plant is influenced by several factors which are meteorological factors, soil moisture and the physiology of the plants. Meteorological factors includes temperature, humidity, solar radiation and wind speed [11]. Research conducted showed that FAO56 Penmann-Monteith formula (1) produces the output with the highest accuracy to the actual evapotranspiration and suitable for both dry and humid regions [12]. However, taking the crop physiology and soil moisture into consideration, the actual crop evapotranspiration value is given as (2) [13].

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{(T+273)}U_2(e_a e_d)}{\Delta + \gamma(1 + 0.34U_2)} \quad \ldots (1)$$

where ET_0 = potential ET
T = air temperature
G = heat soil flux density
U_2 = average wind speed
e_a = water pressure
e_d = vapour pressure
R_n = radiation net value
γ = thermometer constant

Actual crop ET = *Potential ET* x *Crop Physiology* x *Soil Moisture* … (2)

2.5 Management of water supply to crop

According to research, there is an optimum time of the day to water the plants. This time is during the early mornings, before the temperature begins to rise as well as in the late afternoons. However, when watering the plants in the late afternoons, is best to be allow the excess water to dry before sundown. This is to prevent fungal development in the crop [16].

When watering potted plants, it is important for the water to reach the root-zone area. Consequently, the volume of water needed to be supplied is enough when some of the water drains out in the bottom of the pot. The amount needed may vary according to the size of the pots. To ensure that the water reaches the root-zone, allow the water to be soaked into the soil before repeating the process until some water is drained out of the bottom of the container [17].

In every system, a certain management system is implemented to irrigate the water supply to the crop. Sprinkler irrigation and drop irrigation usually practices a timer clock where the crop is irrigated several times a day according to the settings set

in prior. In a more sophisticated system, fuzzy logic controller or artificial neural network (ANN) is implemented. Although many researches has been conducted implementing fuzzy logic and ANN in irrigation system, it is not widely implemented in real field application.

2.6 Conclusion

In conclusion, there are different types of technology developed in agriculture. Each varies according to the application in the field. In agriculture, it is important to know how the water is supplied to the crop, when is the optimum time for watering as well as how much water is needed by the crop. These main characteristics are able to be identified by understanding the evapotranspiration rate of the plant and the water loss it encounters in the process.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

The focus of this project is to develop an irrigation system controller to achieve the objectives successfully. This chapter explains in detail about the hardware and software requirements of the research conducted. The concept of the whole system is explained in detail and is broken down to three main components which are the sensors, data acquisition controller and the water irrigation system. These three components will be integrated with one another to create an end capillary irrigation system controller. The challenge of the project is to develop a system that manages the irrigation system with the environment changes in real time. The irrigation system controller developed will only supply water to the plant according to the water demand.

3.2 System Overview

This system develops a capillary irrigation system using a suitable material as the medium for water transport and implements several sensors to obtain the crop surrounding changes such as humidity, temperature and soil moisture as part of the management system. Taking the crop characteristics into consideration, the sensor input will used to measure the potential and actual evapotranspiration rate and identify the crops' water needs. This will be processed in the data acquisition controller and an output will be produced to signal the water irrigation system to yield the water level of the capillary irrigation according to the real-time crop environment condition. The water level of the capillary irrigation reflects to the volume of water supplied to the plant. More water is supplied in a high water level as compared to a low water level. Figure 3.1 shows the flow of the capillary irrigation system controller.

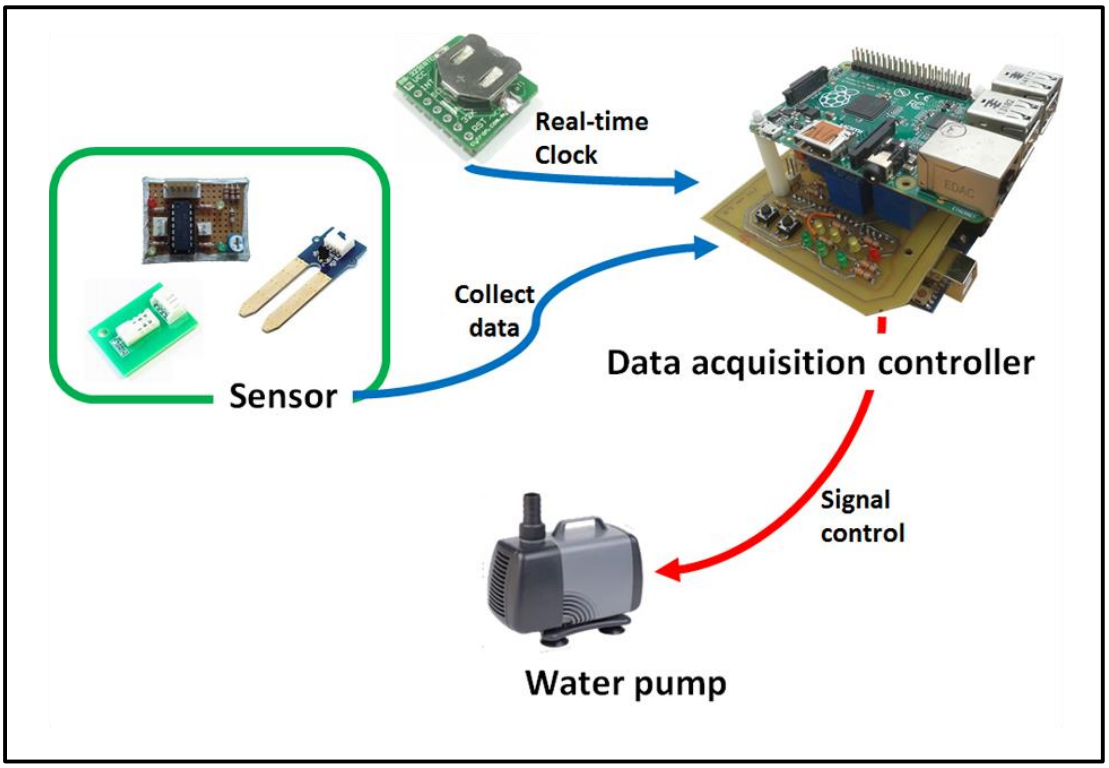

Figure 3.1 Flow of irrigation system

3.3 System Implementation

Capillary irrigation is implemented in this system as a method to water the plants. There are many types that can be used as a medium for the capillary irrigation such as water string, soil and etc. The main reason as to why capillary irrigation method is chosen to be implemented in this system is because it has a low water loss compared to other irrigation methods.

The most common medium for the water transportation applied in capillary irrigation are water wick (water string) and soil wick. Using soil as a medium in capillary irrigation requires a tube to allow the soil to partially soak in the water source. In doing so, the plant is not totally immersed in the water source and receive excessive water. A water string connects the soil to the water source. The setup of the water string is shown in Figure 3.2.

Figure 3.2 Water string setup in a pot

The same concept of how the water supply is absorbed by the plants via roots and released into the atmosphere is applied for both soil and water string in capillary irrigation. Every plant will have a root-zone area surrounding the roots where capillary attraction will pull the water content in the soil towards the roots. This attraction will move against the gravitational force. The water supply will be absorbed by the capillary and move through the soil towards the root-zone. Water absorbed by the roots will undergo the transpiration process while the water molecules in the surface of the soil will experience evaporation. Both processes is known as evapotranspiration. The process flow of how water travels in the capillary system is viewed in Figure 3.3.

Figure 3.3 Water flow in capillary irrigation

Implementing the capillary irrigation method in this project requires the control of the height of the water supply. To control the water level in several pots of plants at the same time in a capillary irrigation requires a parallel piping setup. Ensuring that the water level in every pot is the same by installing a water level sensor in each pot is not practical as this is costly. Therefore, to guarantee that the height of water level is the same, Bernoulli's principle is applied. Bernoulli's principle states that in a steady flow, the sum of energy flow along a streamline is the same. For the water level height to be the same in each pot, it must be positioned levelled with the water supply and the pots that are connected in parallel.

The approach in conducting this project is by installing the capillary irrigation system using the water string. The setup of the experiment is shown in Figure 3.4. The water management in this irrigation system is done by controlling the height of the water level, h as circled in red in Figure 3.4. The setup requires two water tanks, one to control the water level height and another as the main water supply. The water level sensor is placed in the water supply tank connected in parallel with the pots while the water pump is placed in the main water supply tank. The soil moisture sensor is placed in one of the pots, lodged in the soil. Temperature and humidity is measured by placing the sensor near the experiment area. Considering that the type of plants used, area of experiment and age of the plant is the same, there is an assumption that the rate of evapotranspiration for the plants involved is equal. Furthermore, the experiment is placed in a controlled greenhouse environment. Thus, if it rains, the rain water will not enter the pots.

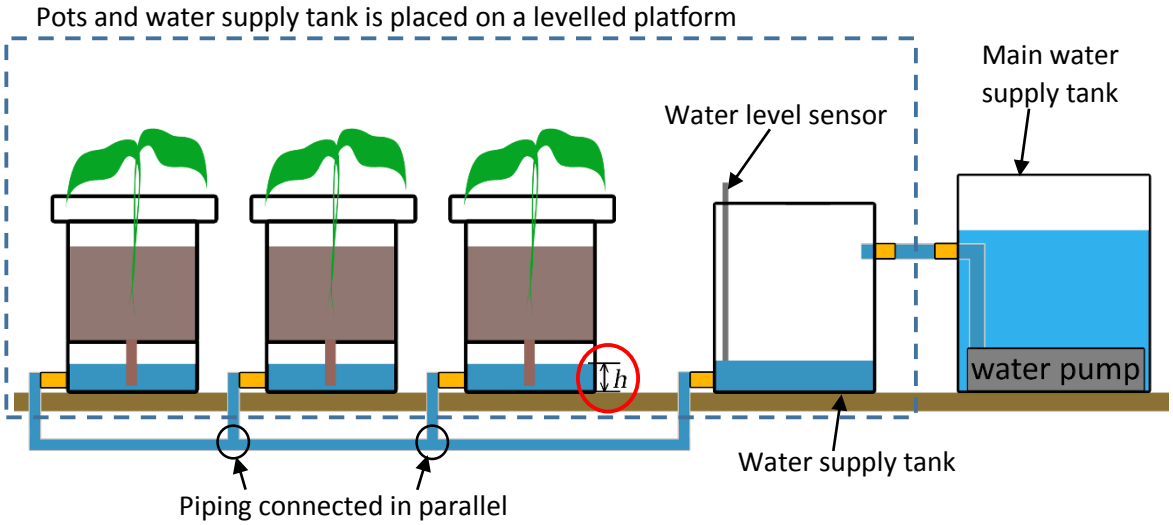
Pots and water supply tank is placed on a levelled platform
Main water supply tank
Water level sensor
water pump
h
Water supply tank
Piping connected in parallel

Figure 3.4 Project setup

The list of components required to execute this experiment is as shown in Table 3.1.

Table 3.1 List of components

No	Item	Quantity
1	Arduino Uno	1
2	Raspberry Pi B+	1
3	DS3231 RTC Module	1
4	HSM-20G Humidity Sensor Module	1
5	SEN0114 Moisture Sensor	1
6	Water level sensor	1
7	Power cable	1
8	Adapter 12V 1A	1
9	Wiring	
10	Water tubing and connectors	
11	Water pump	1
12	Water tank	2
13	Waterproof box (for circuit placement)	1
14	Seeds	
15	Planting pots	

The temperature and humidity sensor requires calibration before being able to be applied in the system. The calibration of each sensor is calibrated according to the general algorithm in equation (3).

$$Calibrated\ data = \frac{Analog\ input + Sensor\ Constant}{1024} \times Sensor\ ref \qquad \ldots (3)$$

Using the serial monitor, the analog values of the temperature and humidity sensors are sampled at selected temperature and humidity using a thermometer and a humidity gauge as the reference values. The sampled data is plotted into a graph to identify the sensor constant.

Figure 3.5 shows the flowchart of the main controller, Arduino. Upon powering on, the system is initialized where the settings of the input and output pin is declared and the initial conditions are set. Once it is initialized, the program will sample the analog value reading from the sensors. Using equation (3) as reference, the sensors are calibrated where the temperature, humidity and soil moisture is determined. The water level value is determined as shown in flowchart in Figure 3.6. With the environment data obtained, the potential and actual evapotranspiration rate is measured.

The controlling of the water level, h indicates the amount of water supplied to the crop. As the water level increases, more water is supplied to the crop. In this project, the desired water level value is identified by the difference in the potential evapotranspiration and actual evapotranspiration value as shown in Figure 3.7. When the need for water supply is greater than the amount of water supplied, the desired water level increases to ensure that the crop is receiving the same amount as its' demand. Meanwhile, when the actual evapotranspiration value is greater than the potential evapotranspiration value, the water level should be low as it is receiving more water than it needs.

When both water level value and the desired water level value is known, the values are compared. If the values are the same, the water pump is not turned on. However, if the water level is less than the desired water level, a signal will be sent to

actuate the water pump. All the data obtained is then sent to serial for the Raspberry Pi for logging purposes. This process is then repeated.

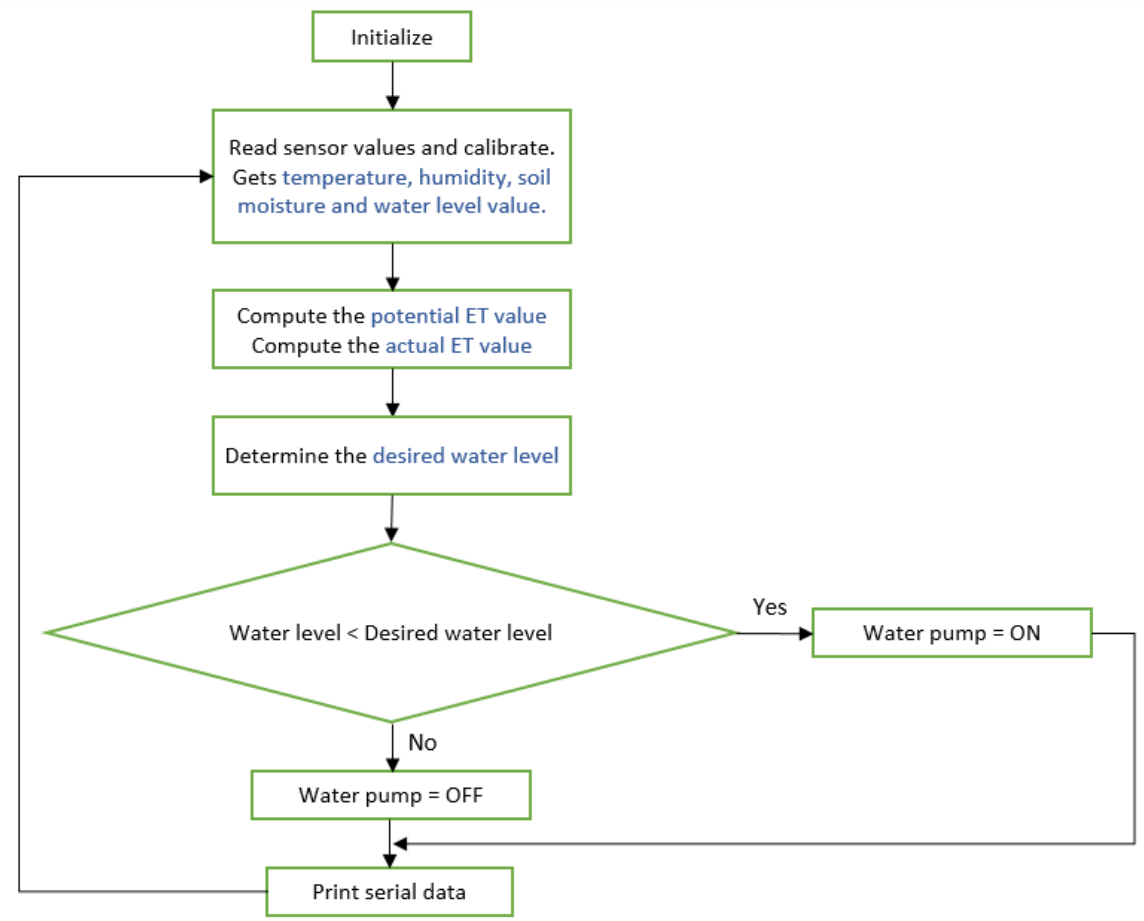
Initialize
Read sensor values and calibrate. Gets temperature, humidity, soil moisture and water level value.
Compute the potential ET value
Compute the actual ET value
Determine the desired water level
Water level < Desired water level
Yes
Water pump = ON
No
Water pump = OFF
Print serial data

Figure 3.5 Overall Arduino code flowchart

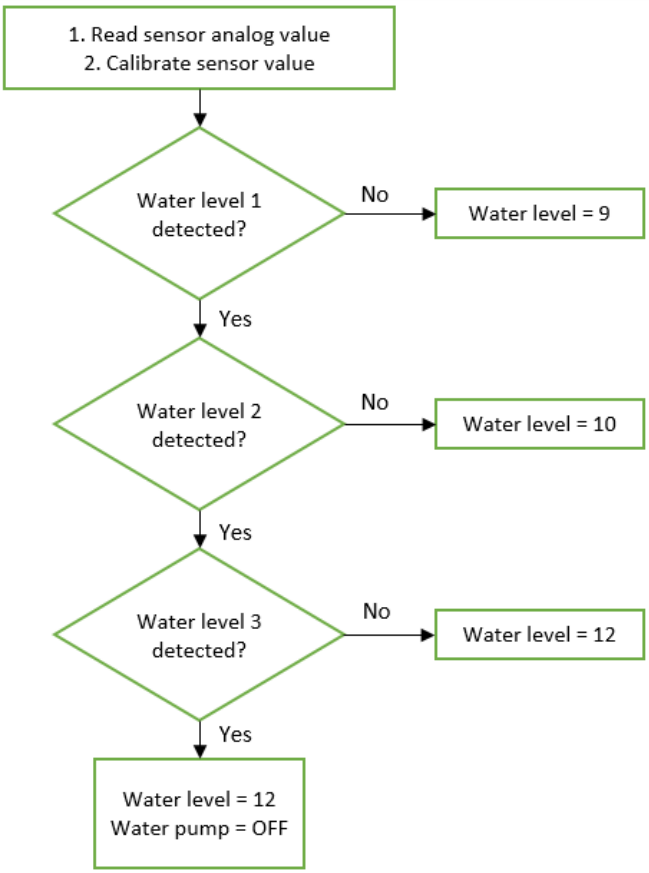

Figure 3.6 Flowchart of Arduino code in determining the actual water level

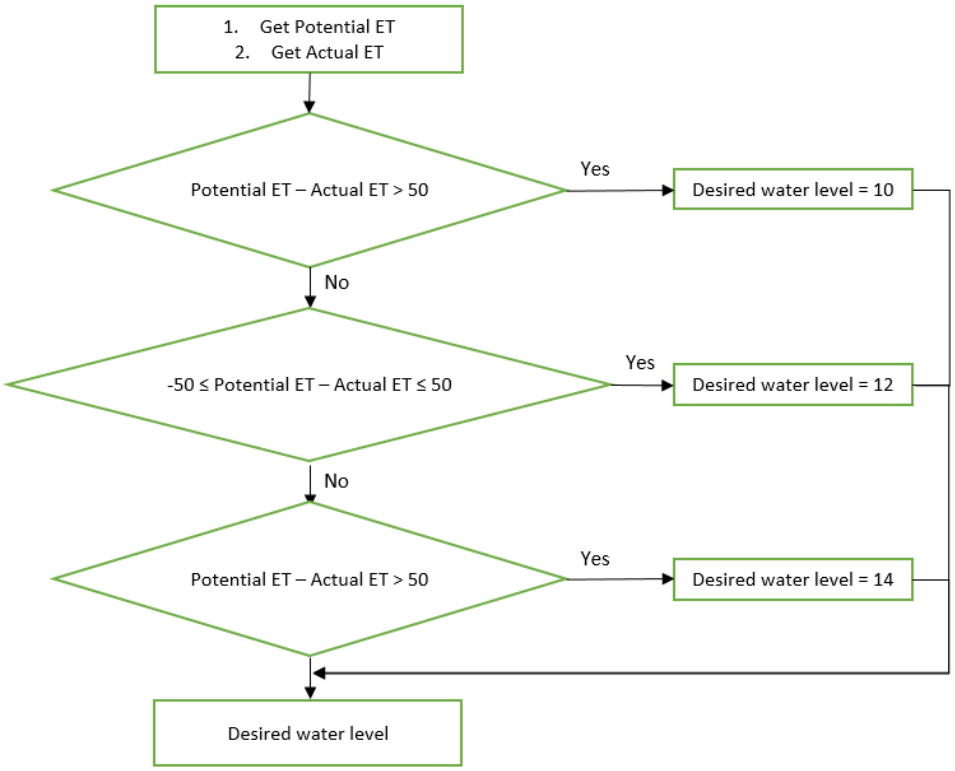

Figure 3.7 Flowchart of Arduino code in determining the desired water level

3.4 System Components

3.4.1 Sensors

I. HSM-20G Humidity Sensor Module

The humidity sensor module is used to measure the relative humidity level and is converted to a standard voltage output. The output voltage for this unit ranges from 1V to 3V enable to measure the relative humidity from 20 to 95 percent and temperature value from 0°C to 50°C. The sensor input is wired to the analog input pin to collect the data. Figure 3.8 shows the HSN-20G Humidity Sensor Module.

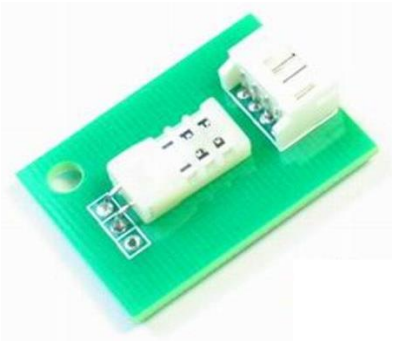

Figure 3.8 HSM-20G Humidity Sensor Module

II. SEN0114 Moisture Sensor

Moisture sensor measures the level of moisture of the soil surrounding it. The two probes is used to pass current through the soil and it evaluates the moisture level based on the resistance reading. The higher water content in the

soil, the less resistance. Therefore, it will give a higher analog value. The value of the soil moisture ranges from 0 to 950 where 0 to 300 is considered dry soil, 300 to 700 is humid soil and 700 to 900 is in water.

Figure 3.9 SEN0114 Moisture Sensor

III. Water Level Sensor

The water level sensor is designed to detect the presence of water. The circuit is designed using a comparator LM324N. The input of the circuit is placed in the water tank to determine the water level. The circuit will give four output of high (5V) or low (0V). Figure 3.10 shows the LM324N used as the main component in the sensor circuit.

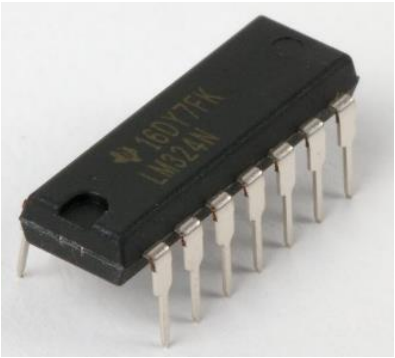

Figure 3.10 Comparator LM324N

IV. DS3231 RTC Module

DS3231 RTC Module were implemented in the system as a real time clock. The module has an internal crystal clock and a switched bank of tuning capacitors. This module sends the data to the main controller using the I^2C interface. A coil cell battery is required to power on the module board.

Figure 3.11 DS3231 RTC Module

3.4.2 Data acquisition Controller

The purpose of the data acquisition controller is to collect the sensor input and convert them to its actual data. The sensor input is calibrated before the data is applied. The controller will then compute the output that will be used to control the valve opening in the irrigation system.

I. Arduino Uno

The Arduino Uno acts as the main processing unit in the data acquisition controller. The data collected from the sensor input uses the analog input pins. Each of the data input is calibrated in comparison with a calibrated

sensor to ensure accuracy when the data is implemented in the system. Figure 3.12 shows the Arduino Uno board.

Figure 3.12 Arduino Uno

II. Arduino IDE

Arduino IDE is an integrated development environment (IDE) for Arduino products using C programming language. This software is able to support the board used in this research. The coding of data acquisition and output control is written and compiled using this software. Figure 3.13 shows the Arduino IDE interface v1.0.3.

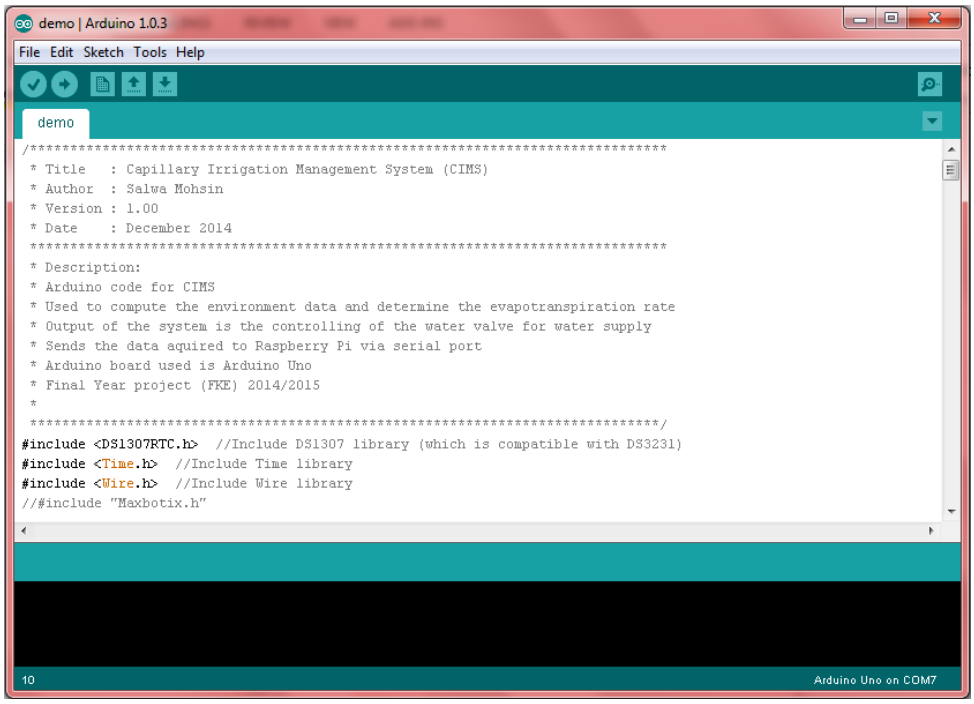
demo | Arduino 1.0.3
File Edit Sketch Tools Help
demo
/***
* Title : Capillary Irrigation Management System (CIMS)
* Author : Salwa Mohsin
* Version : 1.00
* Date : December 2014
****
* Description:
* Arduino code for CIMS
* Used to compute the environment data and determine the evapotranspiration rate
* Output of the system is the controlling of the water valve for water supply
* Sends the data aquired to Raspberry Pi via serial port
* Arduino board used is Arduino Uno
* Final Year project (FKE) 2014/2015
*
***/
#include <DS1307RTC.h> //Include DS1307 library (which is compatible with DS3231)
#include <Time.h> //Include Time library
#include <Wire.h> //Include Wire library
//#include "Maxbotix.h"
10
Arduino Uno on COM7

Figure 3.13 Arduino IDE v1.0.3 interface

III. Raspberry Pi B+

Raspberry Pi is a credit-card sized computer used in the system as a data logger. The Arduino Uno board will send a string of processed data to the Raspberry Pi via serial port every five minutes. The Raspberry Pi will log the data received in a file for monitoring purposes. Figure 3.14 shows the Raspberry Pi B+ board used.

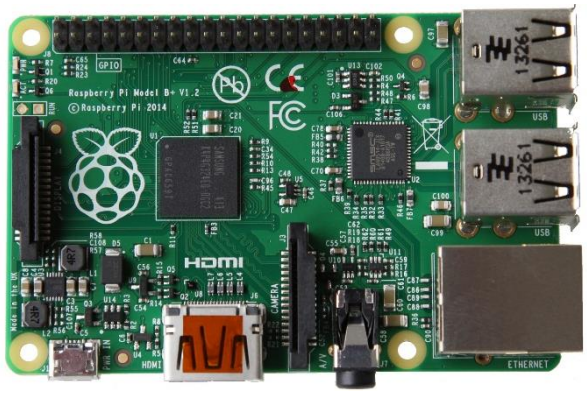

Figure 3.14 Raspberry Pi B+

IV. Algorithm

Figure 3.15 shows the flow of algorithm for the controller. All sensor inputs will be sampled every 15s interval. Once the input is sampled, the data will be calibrated and the evapotranspiration rate will be computed. From the potential and actual evapotranspiration rate calculated, the desired water level is determined from the difference value between the potential and actual evapotranspiration rate. The higher the difference value shows that the crop requires more water supplied.

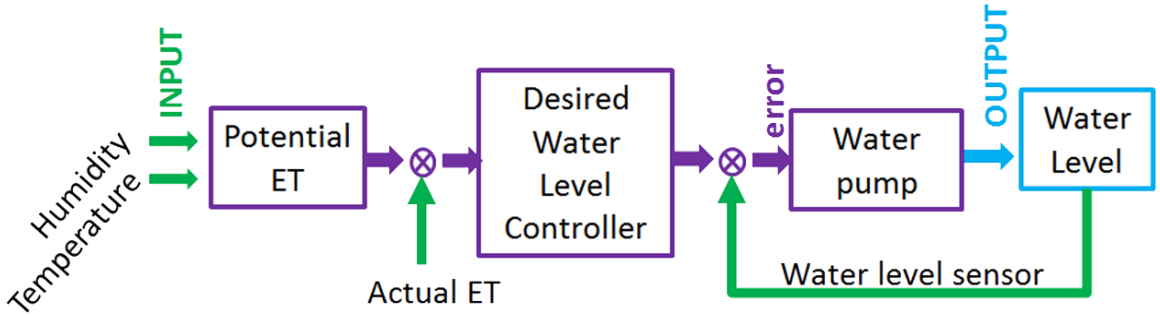

Figure 3.15 Flow of algorithm in controller

The computation of the potential evapotranspiration rate will be calculated using the Penmann-Monteith equation using the calibrated data. Although the Penmann-Monteith equation considers many environment factors, in this project, the equation is simplified to consider the three factors which are temperature, humidity and soil moisture.

V. Data logging

The data computed in the main controller is sent to the Raspberry Pi via serial. The code to run the data logger is set to run automatically upon startup of the Raspberry Pi. The data is logged in a file. The parameters of the string sent are: date, time, temperature, humidity, soil moisture ratio, potential evapotranspiration, actual evapotranspiration, desired water level and actual water level. Figure 3.16 shows the flowchart of the programming to data log the serial data received.

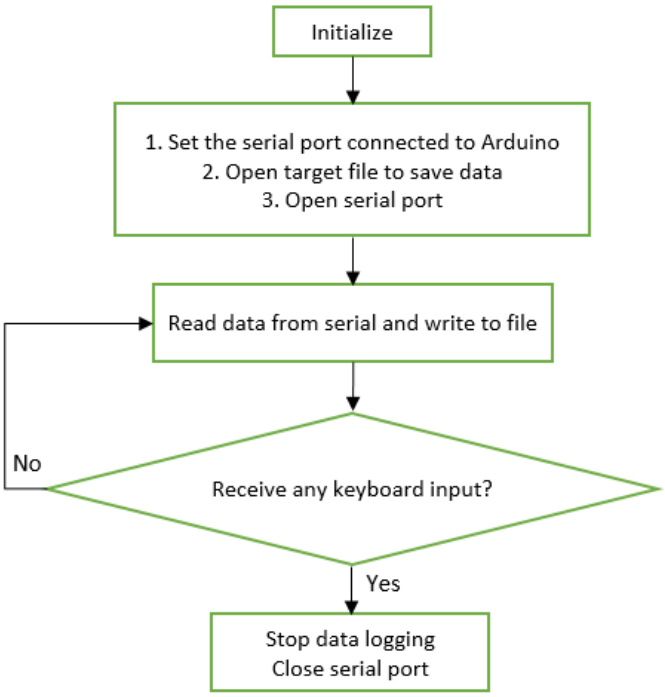
Initialize
1. Set the serial port connected to Arduino
2. Open target file to save data
3. Open serial port
Read data from serial and write to file
No
Receive any keyboard input?
Yes
Stop data logging
Close serial port

Figure 3.16 Raspberry Pi code flowchart

3.4.3 Water irrigation system

I. Water pump

Difference in the desired water level and the actual water level from the sensor will yield and error which will determine the actuation of the water pump. The water pump is powered by an AC power supply. This is powered on or off by the signal received by the main controller. The water pump will allow water to flow from the main water supply tank to the water supply tank.

II. Capillary irrigation

A small narrow tube is connected from the water supply tank and each pot in parallel. The water level of the water supply is monitored in real-time using a water level sensor. The sensor will send the current water level data to the controller. If the water level is lower than the desired water level, the water valve will remain opened until the water level has reached the desired value. The water will flow evenly to each pot until the height of each water level is the same.

III. Test plants

The seeds of the plant is sown prior to the implementation of the system. It is conducted in parallel with the development of the system. Cucumber seeds were sown in small containers placed indoor on the 23rd march 2015. Each container was placed with three seeds.

Figure 3.17 Container of sown seeds

3.5 Conclusion

In implementing the system, the understanding of the water flow is important to ensure that the water supply reaches the plant. Furthermore, the installation of the piping and water tank needs to be checked thoroughly to avoid any water leakage. The wiring of the sensors and the controller needs to be waterproof as the system is implemented outdoors. This is to avoid any short circuit. Most importantly, the time management needs to be planned carefully. This is so that by the time the plant is ready to be transferred and implemented with the system, the system is ready.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, results of the project is presented in pictures and charts. It is then analyzed and discussed. During the execution of the project, the challenges and issues faced are also discussed in detail.

4.2 Results

4.2.1 System components

4.2.1.1 Water level sensor

The water level sensor is designed compact and small for easy implementation on the water tank. This sensor is designed and built instead of purchased to reduce the cost. Figure 4.1 shows the complete water level sensor circuit.

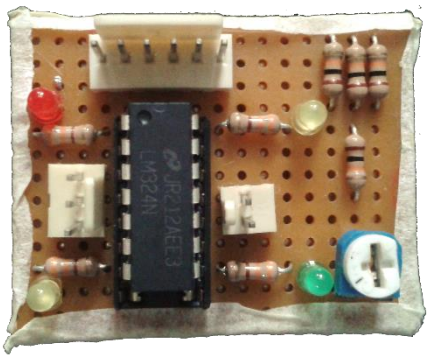

Figure 4.1 Water level sensor

4.2.1.2 Data acquisition controller

Figure 4.2 shows the data acquisition controller stacked onto one another to reduce space. The controller is placed in a waterproof box as a precaution to avoid from getting wet. A shield is developed for the Arduino Uno to enable secure wiring. Furthermore, the shield is designed with valve drivers, LEDs, push buttons and a power jack. The valve driver is directly connected to certain Arduino pins to actuate the water pump. The power jack is connected to the valve drivers to power the water pump. Apart from that, LEDs are installed as indicators.

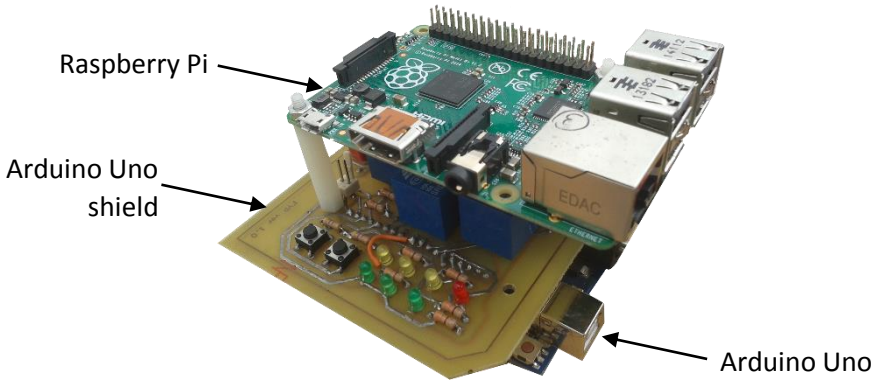

Figure 4.2 Stacked controller

The temperature and humidity sensors implemented was calibrated to identify the sensor constant. Table 4.1 and 4.2 shows the sampled analog values of the temperature and humidity sensors respectively.

Table 4.1 Sampled analog value for temperature sensor

Temperature (°C)	**Analog value**	
	Sample 1	**Sample 2**
29	211	213
30	227	228
31	236	239
33	283	284
35	330	333
40	421	423

Table 4.2 Sampled analog value for humidity sensor

Humidity (%)	**Analog value**
48	267
68	463
75	479

Figure 4.3 and 4.4 shows the graph plotted to determine the sensor constant for the temperature sensor and the humidity sensor. The sensor constant is obtained by the gradient of the graph drawn which touches most of the plotted points.

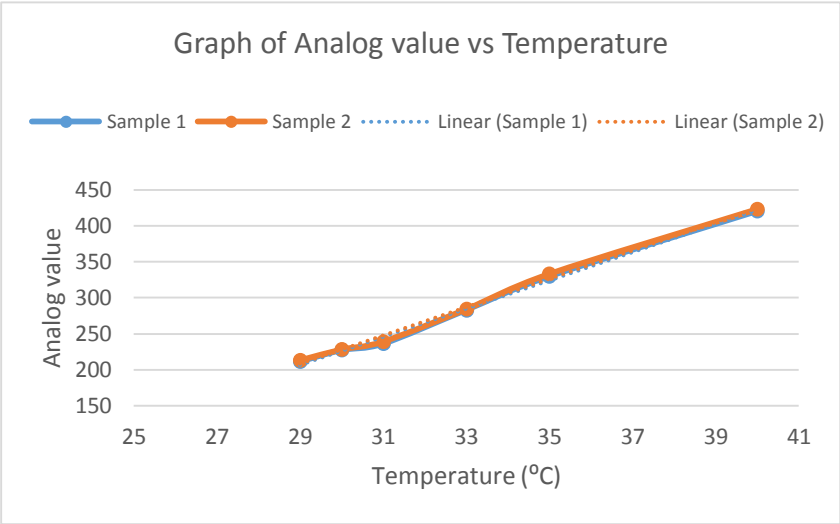

Figure 4.3 Graph of analog value vs temperature

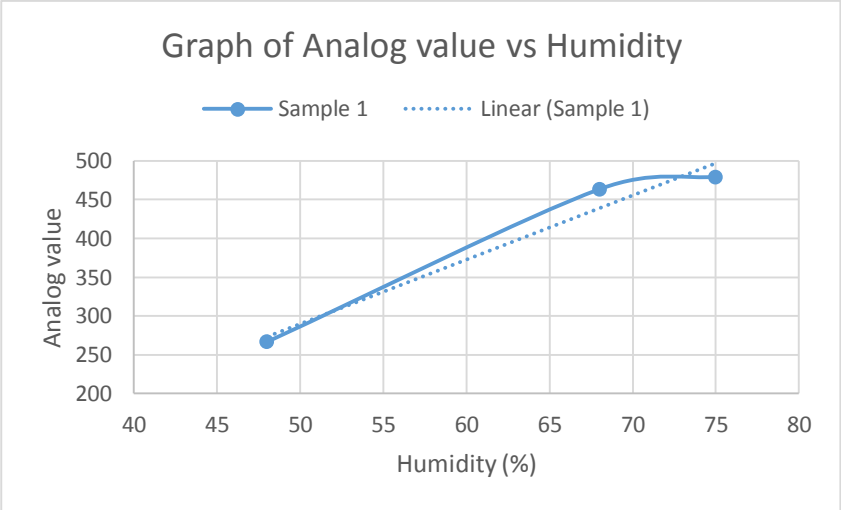

Figure 4.4 Graph of analog value vs humidity

4.2.1.3 Test plants

The plants grew up to 10 centimeters tall as of 16th April 2015 (24 days old). The average leaf count on each stalk was 4 leaves and it is ready to be transferred into a larger pot. Figure 4.5 shows the cucumber plant (right) on 16th April 2015.

Figure 4.5 Cucumber plant (right) on 16th April 2015

4.2.2 Capillary Irrigation System Controller

The system was implemented in a greenhouse. A greenhouse was built and completed on the 26th April 2015. Upon the completion of the greenhouse, the system developed was implemented. Figure 4.6 shows the greenhouse of the project implementation.

Figure 4.6 Greenhouse of the experiment test bed

The setup of the system in the cucumber plant located in the greenhouse is shown in Figure 4.7, 4.8, 4.9, 4.10, 4.11 and 4.12.

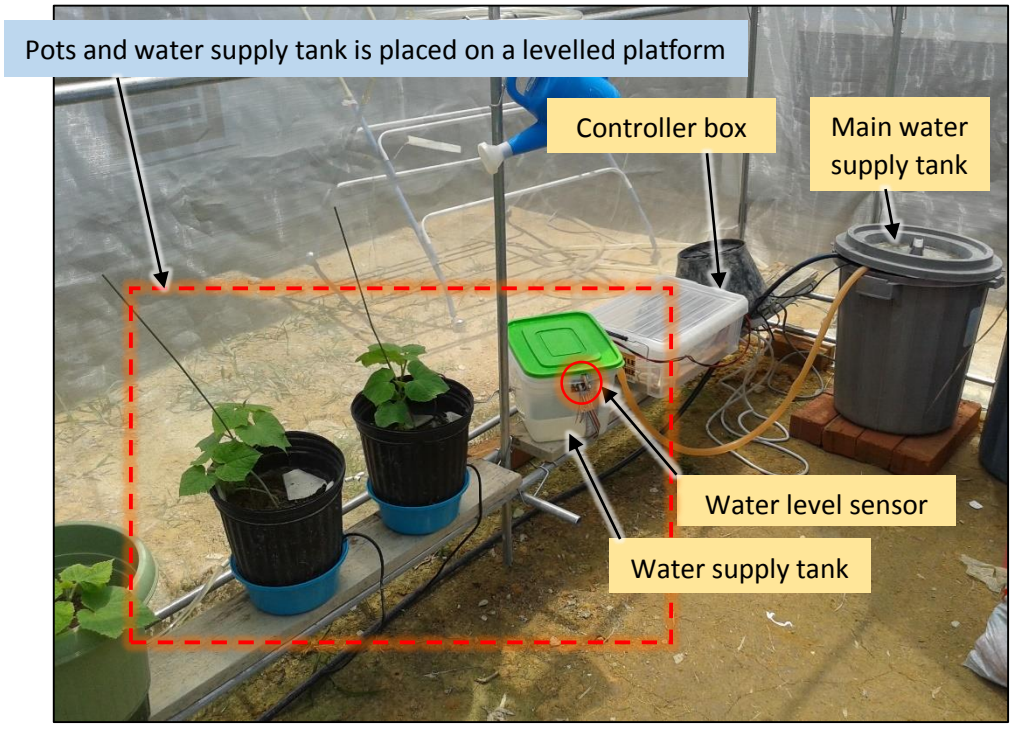
Pots and water supply tank is placed on a levelled platform
Controller box
Main water supply tank
Water level sensor
Water supply tank

Figure 4.7 Overview of the implemented system

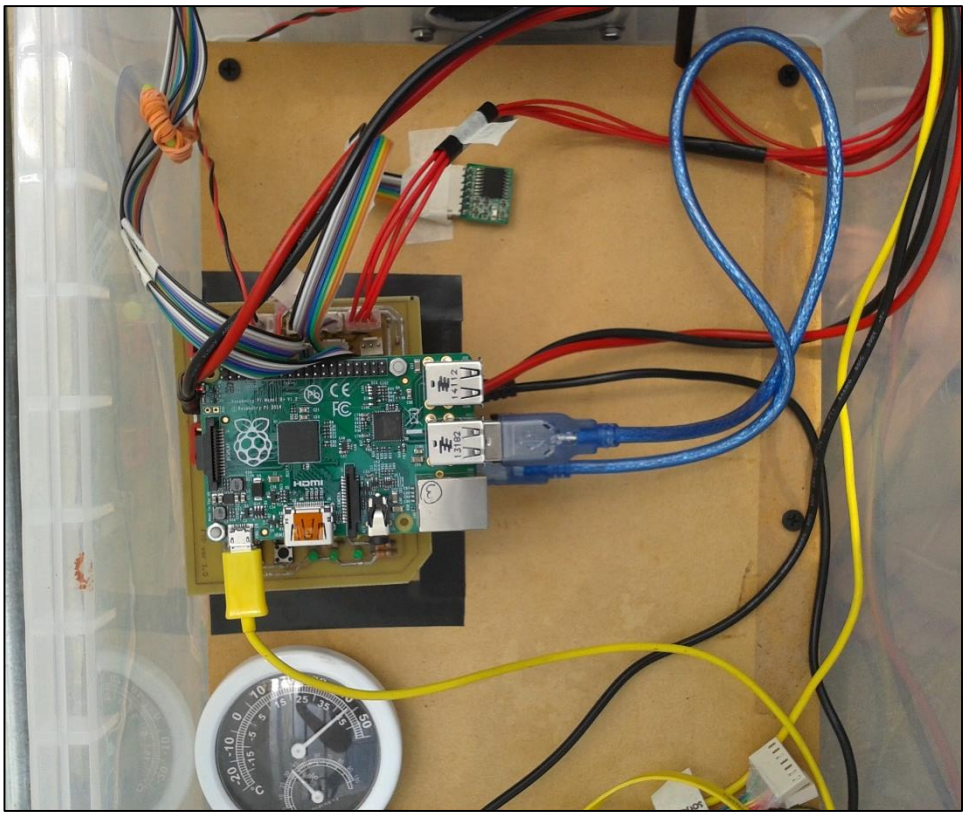

Figure 4.8 Controller placed in a waterproof box on test site

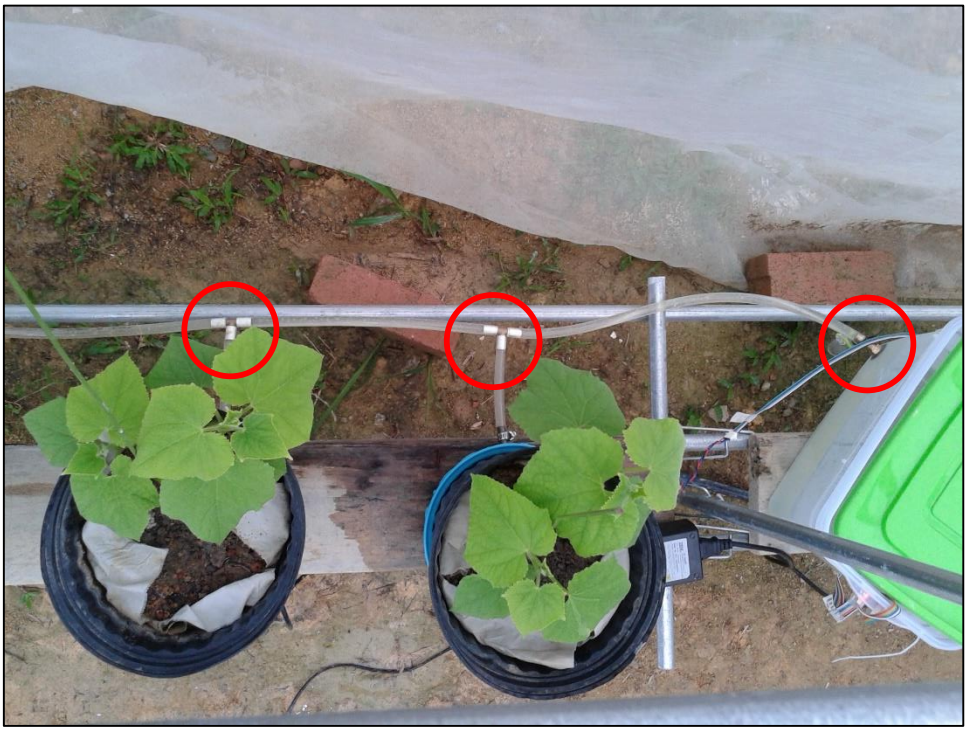

Figure 4.9 Piping of the plants connected in parallel to the water tank

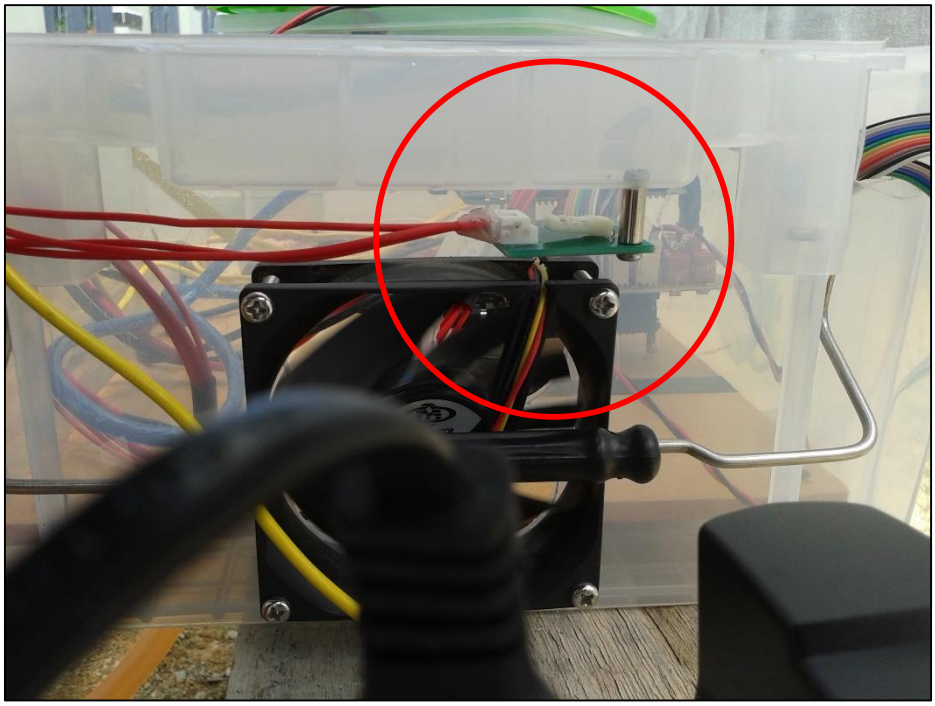

Figure 4.10 Temperature and humidity sensor placed outside the controller box

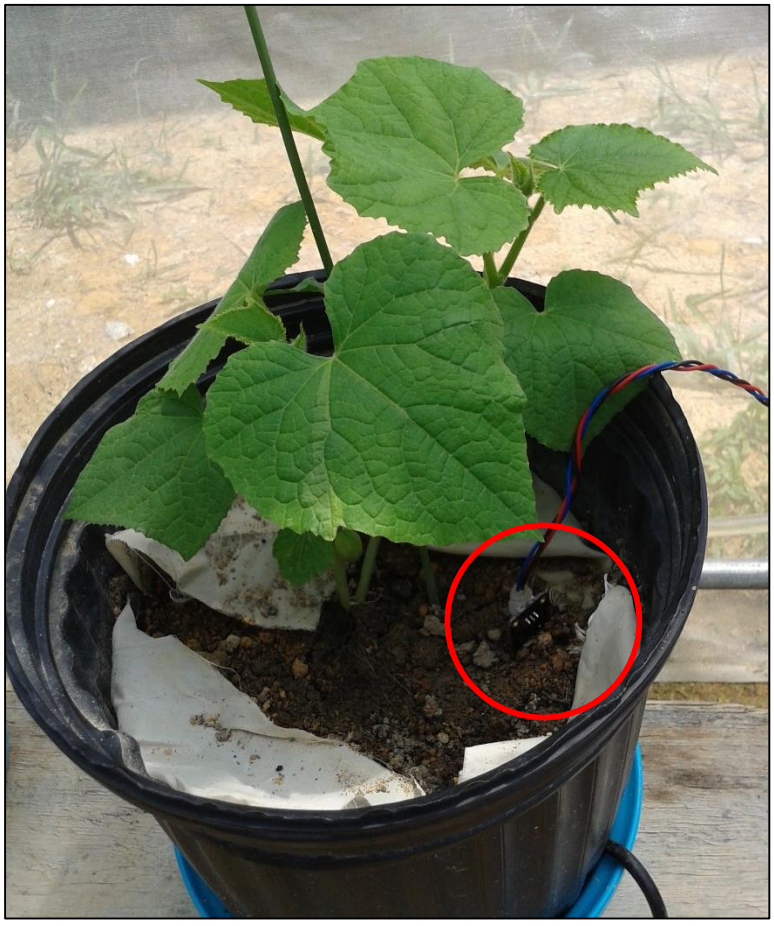

Figure 4.11 Soil moisture sensor lodged in soil in one of the pots

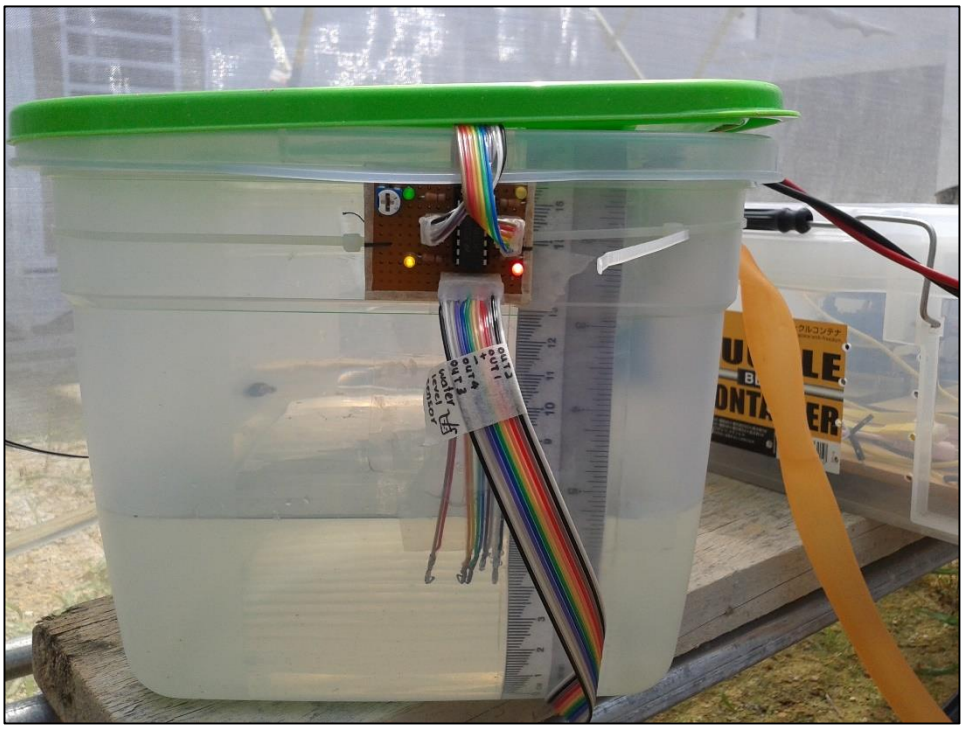

Figure 4.12 Water level sensor implemented on water supply tank

4.2.3 Data logging

The data logging code run in Raspberry Pi logs data sent by Arduino via serial every 5 minutes. Figure 4.11 shows an example of the data logged in a file. Each time data is logged, it starts in a new line and the parameter received is separated by a semicolon. The data logged in the file is presented in a line graph using Microsoft Excel as shown in Figure 4.12 and 4.13.

loggedData4 - Notepad

File Edit Format View Help

DD/MM/YY; HH.MM; temp; humidity; soil moisture ratio; desired ET; actual ET; desired water level; actual water level;

```
15/05/15; 14.14; 28.39; 78.00; 0.81; 243.57; 237.50; 12; 12
15/05/15; 14.19; 28.29; 79.00; 0.81; 245.87; 240.86; 12; 14
15/05/15; 14.39; 28.52; 79.00; 0.81; 247.83; 239.58; 12; 14
15/05/15; 14.44; 28.51; 78.00; 0.81; 244.59; 236.86; 12; 12
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15/05/15; 15.24; 29.17; 78.00; 0.81; 250.29; 238.13; 12; 12
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15/05/15; 16.24; 29.02; 78.00; 0.81; 248.97; 235.91; 12; 14
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15/05/15; 16.39; 28.73; 78.00; 0.81; 246.52; 236.23; 12; 12
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15/05/15; 17.14; 28.89; 79.00; 0.81; 251.02; 238.61; 12; 12
```

Figure 4.13 Example of data logged in a file

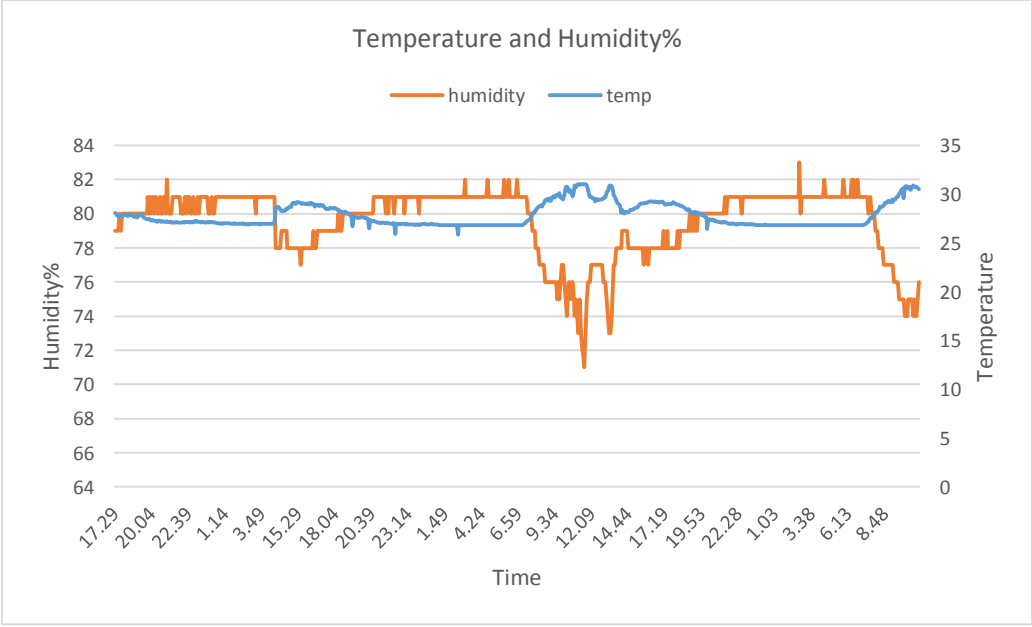

Figure 4.14 Graph of Temperature and Humidity against time based on the data from Figure 4.13

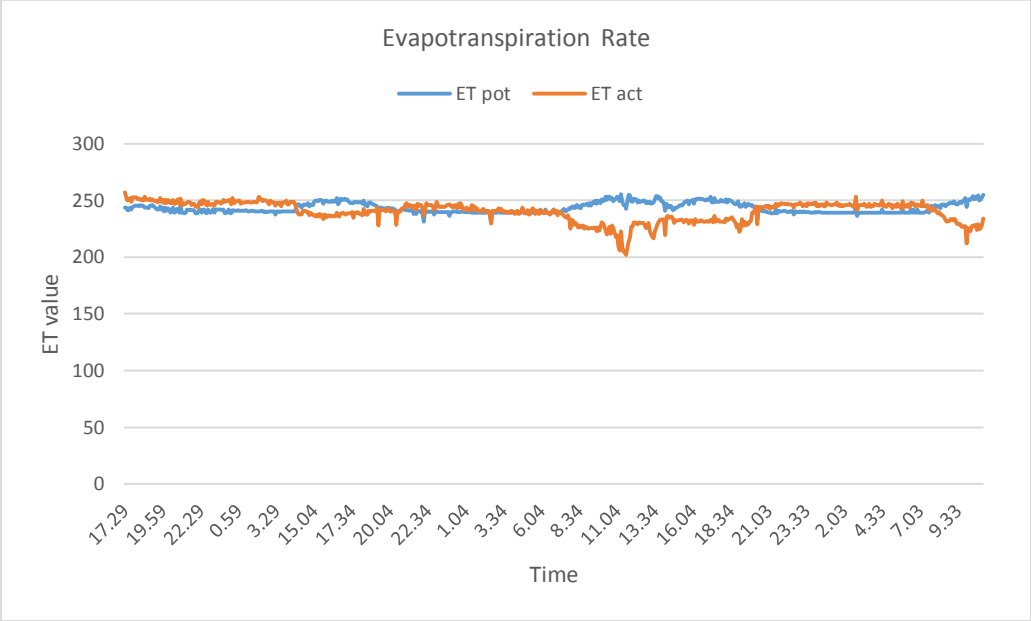

Figure 4.15 Graph of evapotranspiration rate against time based on the data from Figure 4.13

4.3 Discussion

4.3.1 System component

The sensors implemented in the system were chosen based on the requirements of the system. However, the water level sensor was designed to reduce the cost of the project. The water level sensor shows consistent results when detecting the presence of water. It is able to detect four different water levels. LEDs were implemented on the circuitry as indicators of the output to be sent to the main controller. When the sensor detects water, the LED will light up according to the respected water level.

The shield of the Arduino developed is fabricated in printed circuit board (PCB). This is to ensure secure connections between the sensors and Arduino pins. The connections and valve driver developed on the shield has reached good stability

and reliability. LEDs implemented were used as indicators for the valve driver. When a signal is given, the LED is turned on, indicating that the valve driver is turned on.

All of the test plants sown grew according to the time limit as planned. The plants were transferred to a larger pot placing two seedlings in one pot.

4.3.2 Capillary Irrigation System Controller

4.3.2.1 Operation manual

To operate the developed system requires several step. The steps are as the following:

i. Connect all power sources to the socket.
ii. Power on the Arduino
iii. Power on the Raspberry Pi

It is important to power on the Arduino prior to Raspberry Pi. This is to allow the Arduino board to initialize. The data logging system will automatically start logging the data upon start up.

4.3.2.2 Results

The system design is to be implemented in a closed area. Due to the delay in building of the greenhouse, the system implemented on the plants was also delayed. Although the seedlings were transferred to a larger pot on the 16th April 2015 and the greenhouse was completed on the 26th April 2015, the

system was unable to be implemented immediately. There were several glitches in the programming of the system. This caused the system to be applied on the crop later on the 8th May 2015. In the duration of the absence of the system to be implemented, the crop was irrigated using the drip irrigation method. Table 4.3 shows the plants growth throughout the experiment.

Table 4.3 Cucumber plant growth chart

	Task	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13
1	Seeding of the cucumber plant													
2	Plant has sprouted (2 leaves) • Continues to grow in small pot													
3	Transfer to a larger pot • Continues to grow in large pot													
4	Implementation of system													

Due to the lack of time frame, the results of the research was collected for a duration of 10 days. This also resulted to the unavailability to measure the crop outcome as it requires several months to grow the crop and compile the data.

Despite the issues faced, the capillary irrigation system controller developed successfully in terms of that it is able to water the crop on its own varying the water level height according to the environment change. However, occasionally the system is not able to control water level. Controlling the water level refers to the actuation of the water pump. For example, although the water level sensor yields a signal to indicate that it has reached the same level as the desired water level, the water pump does not receive any signal to switch off. This is suspected to be due to the unstable wiring connection between the water level sensor developed and the Arduino shield. In any case that the connection is faulty, it will cause the failure for the controller to receive the current water level signal, and thus causing the value in the system not updated and not signal is set off to turn off the water pump.

4.3.3 Data Logging

The Raspberry Pi data logger is written in python language. The program automatically runs at the startup. To do so, there were several settings that needed to be modified such as the serial port. Configuring the serial port, the serial port that is connected to the Arduino needs to be identified so that the data logger is reading from the correct port.

To log the data received, the data logger opens a file and writes the data. Once it is written, the data will be saved. The next occurring data will append the initial file. Therefore, all the data received will be saved into one file.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

Chapter 5 will draw the conclusion of the research conducted. Besides that, recommendations on how the project could be improved will be shared and discussed in this chapter. Recommendations made are either from the problems faced in conducting this project and how to overcome it or suggestions from a third party who is familiar with this project.

5.2 Conclusion

In this project, the Capillary Irrigation System Controller has been successfully built. With this system installed, plants is irrigated automatically and is watered

according to the plant water demand. Users can monitor the evapotranspiration rate of the plants as well as the environment change.

To conclude, the objectives of the project is achieved. With only irrigating the plants according to the environment change, we hope that the water consumption in the agriculture sector is reduced.

5.3 Recommendation

There are several improvements that can be made in this project for future research. Firstly, the water level sensor used should be designed using the printed circuit board once it reaches a stable performance. For a more advance performance, design the water level sensor that yields an analog output for a more accurate data. Besides that, the Raspberry Pi can be more utilized by implementing an online monitoring system. In doing so, users are able to monitor the data logged anywhere by simply accessing a webpage. Lastly, a sensor can be implemented in the main water supply tank. The purpose of the sensor is to measure the water consumption of the system. With this, we are able to measure the volume of water consumed by the plant as well as measure the efficiency of the system in comparison with the crop outcome.

CHAPTER 6

PROJECT MANAGEMENT

6.1 Introduction

This chapter is will present the project planning in conducting this research as well as cost of implementing this system. Project planning includes project scheduling to ensure that the activities are carried out according to the time frame provided. This project was given eight months for research, designing, implementation and testing. The cost estimation in every project management is inevitable. This is to ensure that the project is carried out spending a minimal cost.

6.2 Project Schedule

Project scheduling involves the Gantt chart in two parts: FYP1 and FYP2. This scheduling is planned throughout semester 1 2014/2015 and semester 2 2014/2015. The Gantt chart shows the progress of the project conducted.

Table 6.1 Capillary Irrigation System Controller Gantt chart (FYP1)

	Task	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
1	Choose FYP topic and finalize topic													
2	Background study: • Study how the plants absorb water • How water flows in soil • Identify the conventional watering method in agriculture and its efficiency													
3	Literature review: • Journals/ Thesis: what studies have been made, methods conducted, statistics, improvement													
4	Identify the characteristics important in plant watering • Plant physiology, environment demand, optimum time for watering													
5	Identification of components and method: • Identify the data and sensors needed • How to get the data required													
6	Create the control system • How the data to be manipulated in the control system • How to integrate the control system to the output to water the plants • Identify tools required													
7	Report													
8	Presentation													

Table 6.2 Capillary Irrigation System Controller Gantt chart (FYP2)

	Task	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
1	Create the control system • Fuse the data complied to create a system • Implementation (software and hardware)															
2	System implementation • Testing the system on a subject															
3	Analysis and improvement of system															
4	Presentation															
5	Thesis preparation															

6.3 Cost Implementation

Table 6.3 shows the budget plan for the Capillary Irrigation System Controller. The table displays the hardware requirement and its price list.

Table 6.3 Capillary Irrigation System Controller budget plan

No	Item	Price per unit	Unit	Total price
1	Arduino Uno	RM58.00	1	RM 58.00
2	Raspberry Pi B+	RM127.40	1	RM127.40
3	DS3231 RTC Module	RM37.10	1	RM 37.10
4	HSM-20G Humidity Sensor Module	RM28.00	1	RM 28.00
5	SEN0114 Moisture Sensor	RM23.30	1	RM 23.30
6	LM3234N	RM1.75	1	RM 1.75
7	Electronic component set	RM30.00	1	RM 30.00
8	Power cable	RM3 / meter	2 meters	RM 6.00
9	Rainbow cable 20ways	RM8 / meter	3 meters	RM 24.00
10	Adapter 12V 1A	RM18.00	1	RM 18.00
Total				**RM353.55**

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APPENDIX A

Arduino Uno Main Controller Code

```
/**************************************************************************
*************

 * Title   : Capillary Irrigation Management System (CIMS)

 * Author  : Salwa Mohsin

 * Version : 1.00

 * Date    : December 2014

**************************************************************************
************

 * Description:

 * Arduino code for CIMS

 * Used to compute the environment data and determine the evapotranspiration rate

 * Output of the system is the controlling of the water valve for water supply

 * Sends the data acquired to Raspberry Pi via serial port

 * Arduino board used is Arduino Uno

 * Final Year project (FKE) 2014/2015
```

```
 *

**********/

#include <DS1307RTC.h>  //Include DS1307 library (which is compatible with DS3231)

#include <Time.h>  //Include Time library

#include <Wire.h>  //Include Wire library

//#include "Maxbotix.h"


tmElements_t tm;  //Declare tmElements object to store time & date from DS3231


int led1 = 11;

int button1 = 13;


/* sensor input */

const int rawTemp = A0;

const int rawHumid = A1;

const int rawSonar = A2;

const int rawSoil = A3;

const int waterLevel_LOW = 5;

const int waterLevel_MEDIUM = 3;

const int waterLevel_HIGH = 10;

//int waterLevel_MAX = 2;
```

```
/* actuator output */
int valve_IN = 9;
int valve_OUT;

/* sensor tuned data */
float temp;          //temperature
float humid;         //humidity
float soil;          //soil moisture
int waterlevel;    //height of water level in cm

int tem = 0;

/* algo parameters */
float etpot = 0;
float etact = 0;
float kc = 0.75;
float ks;
float d = 11; //hours of sun exposure
int des_water;
float humid_percent;

int counter = 0;
```

```
void setup()
{
  analogReference(DEFAULT);
  pinMode(rawTemp, INPUT);
  pinMode(rawHumid, INPUT);
  pinMode(rawSoil, INPUT);
  pinMode(waterLevel_LOW, INPUT);
  pinMode(waterLevel_MEDIUM, INPUT);
  pinMode(waterLevel_HIGH, INPUT);
  pinMode(valve_IN, OUTPUT);
  pinMode(4, OUTPUT);

  Serial.begin(115200);
}

void loop()
{

  digitalWrite(4, HIGH);
  while(1){
    readSensor();
    compute_data();

    /* determine desired water level */
```

```
if (etpot-etact > 50){
  des_water = 10;
}
else if (etpot-etact <= 50 || etpot-etact >= -50){
  des_water = 12;
}
else if (etpot-etact < -50){
  des_water = 14;
}

/* assign output */
if (waterlevel < des_water){
  digitalWrite(valve_IN, HIGH);
}
else {
  digitalWrite(valve_IN, LOW);
}

if(counter++ >= 20){
  if(RTC.read(tm)){           //data received from RTC module
    printTime();
  }
  else {                  //data not received from RTC module
    if(RTC.chipPresent()){            //RTC module is connected
```

```
        Serial.println("DS3231 Stop. Load Set Time");
      }
      else {                    //RTC module is not detected
        Serial.println("Error. Check connections");
      }
    }
    printSerial();
    counter = 0;
  }

 }

}

void readSensor()
{
 /* Compute the sensor values */
 temp = (analogRead(rawTemp) - 2887)/-84.33;
 humid = (analogRead(rawHumid) - 1162)/-12;
 soil = (analogRead(rawSoil));

 /* determine water level */
 if(digitalRead(waterLevel_LOW)){
  if (digitalRead(waterLevel_MEDIUM)){
```

```
      if(digitalRead(waterLevel_HIGH)){
        digitalWrite(valve_IN, LOW);
        waterlevel = 14;  //water level >= 14cm

      }
      else {
        waterlevel = 12;    //12cm <= water level < 14cm
      }

    }
    else {
      waterlevel = 10;      //10cm <= water level < 12cm
    }

  }
  else {
    waterlevel = 9;         //water level < 10cm
  }

}

void compute_data()
{
  float etref = 500;
```

```
  humid_percent = humid/100;
  ks = soil/920; //in data/in range
  etact = ks*kc*etref*humid_percent;

  etpot = d*temp*humid_percent;
}

void getTime(unsigned char num)
{
  unsigned char byte_temp;
  byte_temp = num/10;
  Serial.print(byte_temp);
  byte_temp = num%10;
  Serial.print(byte_temp);
}

void printTime()
{
/* Print time in serial */
  getTime(tm.Day);
  Serial.print("/");
  getTime(tm.Month);
  Serial.print("/");
```

```
  getTime(tmYearToY2k(tm.Year));
  Serial.print("; ");
  getTime(tm.Hour);
  Serial.print(".");
  getTime(tm.Minute);
  Serial.print("; ");
}

void printSerial()
{
  /* Serial data send to Raspberry Pi */
  Serial.print(temp);
  Serial.print("; ");
  Serial.print(humid);
  Serial.print("; ");
  Serial.print(ks);
  Serial.print("; ");
  Serial.print(etpot);
  Serial.print("; ");
  Serial.print(etact);
  Serial.print("; ");
  Serial.print(des_water);
  Serial.print("; ");
  Serial.print(waterlevel);
```

```
  Serial.println();


}
```

APPENDIX B

Data Logger Code (Raspberry Pi)

```
import sys, serial,time
from matplotlib import pyplot as plt

# set the serial port the Arduino is connected to
#! /usr/bin/env python

import sys, serial,time
from matplotlib import pyplot as plt

# set the serial port the Arduino is connected to
serPort = '/dev/ttyACM0'

# open the file for writing
```

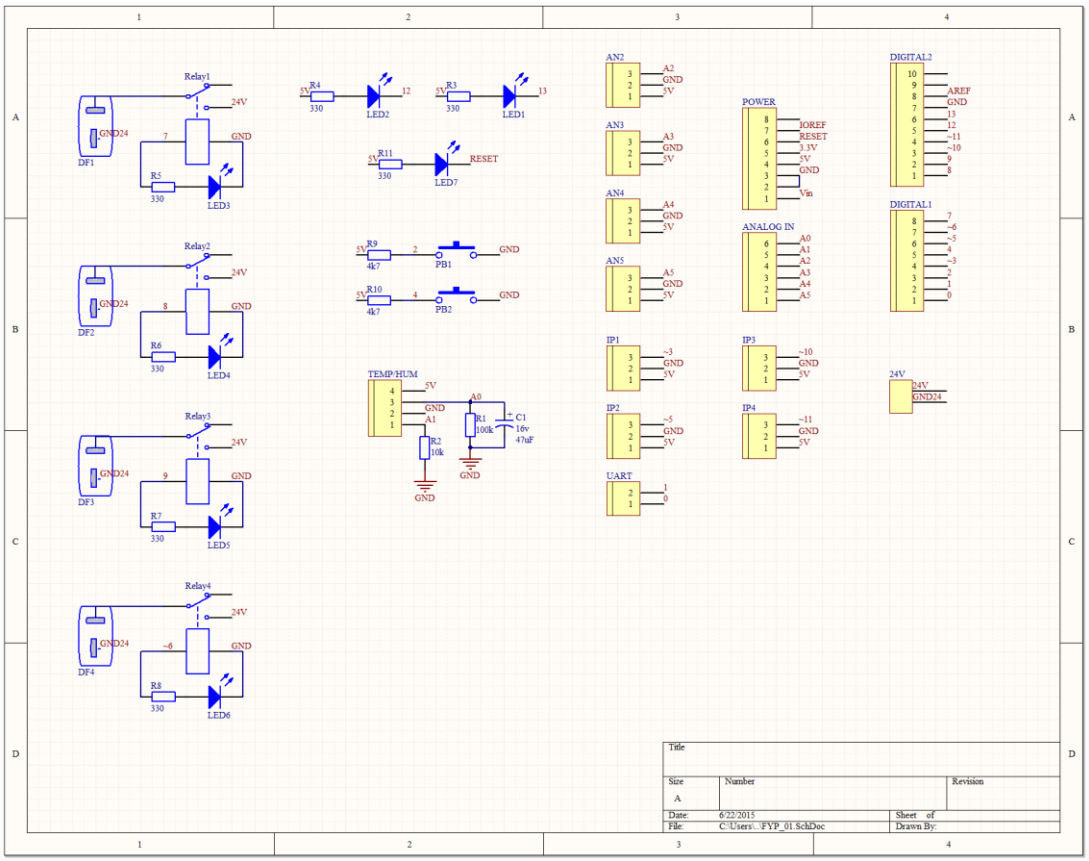
```
dataFile = open("./loggedData.txt","a");


print "\n***********************************************************"
print "\nLog Data"
print "\nAttempting to open Serial Port : ",serPort,"for logging\n"


# opens usb serial port for logging
ser = serial.Serial(serPort,115200)


# checks the port is open
if (ser.isOpen() == False):
    print "ERROR : Unable to open serial port ",serPort,"\n"
    exit(0);
else:
    print "Port ",serPort," opened\n"


# force print to console
sys.stdout.flush()


# waits for signal from user to start logging
##print "Hit return to start logging ..."
##key = sys.stdin.readline()


# sends signal to start logging
```

```
##ser.write('1');
print "Logging Started. CTRL-C to stop\n"

while True:
    try:

        # read data from serial writes to stdio and dataFile
        line = ser.readline()
        print line;
        dataFile.write(line)

    except KeyboardInterrupt: #CTRL-C triggered here

        # sends signal to stop logging
        ser.write('0')

        print "Logging Stopped\n"

        break;

# close the serial port
ser.flush()
ser.close()
```

```
# close the datafile

dataFile.close()


print "Port ",serPort," closed\n"

print "\n**********************************************************\n"


# rest for 3 seconds

time.sleep(3)
```

APPENDIX C

Arduino Shield Circuit Design Connection



APPENDIX D

Water Level Sensor Circuit Design